Flow Changes due to Hydropower Plant Upgrades
Cumberland River Basin, Kentucky & Tennessee

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Abstract

Flow regimes in the Cumberland River Basin in Kentucky and Tennessee will undergo some change as a result of replacing aging turbine/generators at Corps' Dams in the basin. An assessment of downstream riverine impacts requires discharge hydrographs reflecting both existing and new hydropower plants operations. These discharge hydrographs are input to the one-dimensional, unsteady flow model used to route flows through the system. The hydrologic changes form the basis for other physical and biological impacts assessment.

The Hydropower Analysis Center (the author) was tasked with developing hourly, 7-day hydrographs in cooperation with District hydropower program managers. Analyses of observed data, output from the HEC-5 hydropower benefits analysis, and turbine performance characteristics formed the bases for development of these hydrographs.

This paper describes a method used in developing hydrographs for the existing and upgraded hydropower plants.

Introduction

Many of the hydropower facilities in the Cumberland River System of dams are approaching their useful design life (+50 years). See Figure 1 and accompanying Table 1 below.
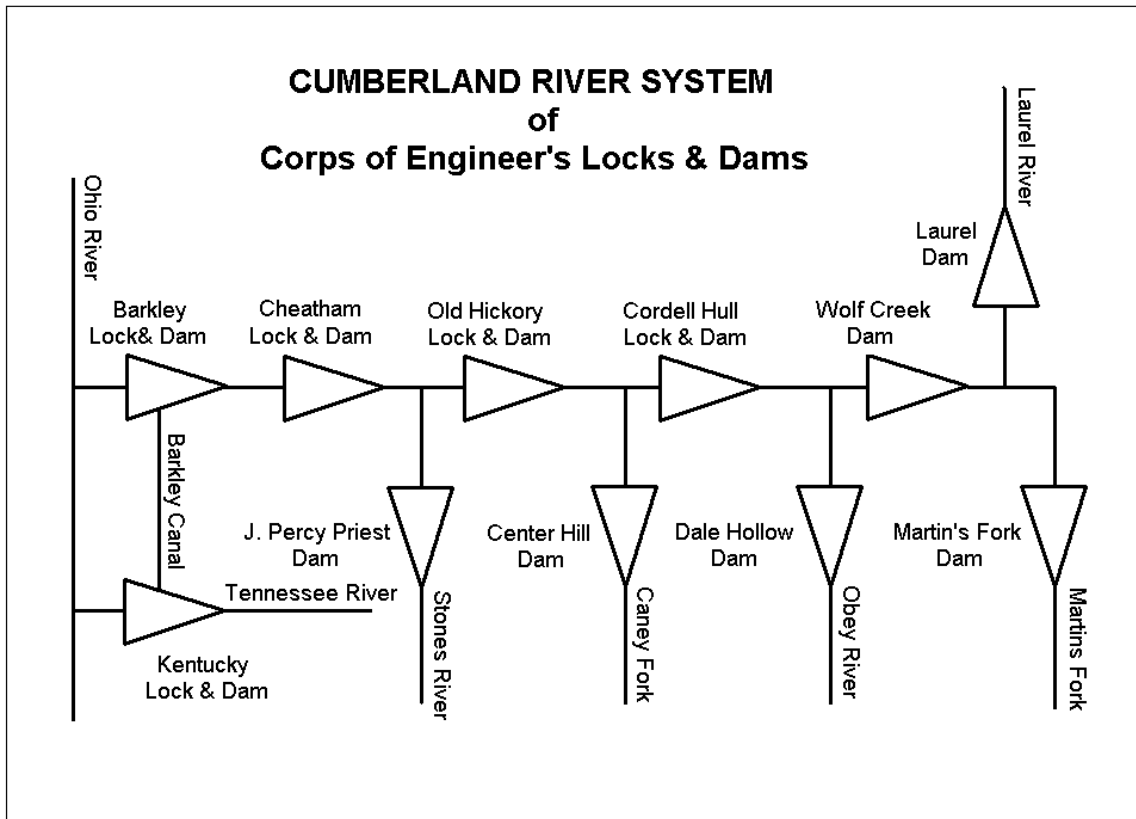
CUMBERLAND RIVER SYSTEM
of
Corps of Engineer's Locks & Dams

Figure 1. Cumberland River System.

Table 1. Cumberland River hydropower plants.

Project	Units	MW	On-Line Date (age)
Barkley	4	130	1966 (37)
Center Hill	3	135	1950 (53)
Cheatham	3	36	1958 (45)
Cordell Hull	3	100	1973 (30)
Dale Hollow	3	54	1948 (55)
J. Percy Priest	1	28	1970 (33)
Laurel	1	61	1977 (26)
Old Hickory	4	100	1957 (46)
Wolf Creek	6	270	1952 (51)

The aging equipment is less reliable than when first installed and consequently the cost of maintenance is rising. There have been technological advances in the design of hydropower turbines and in generators that allows more efficient equipment to be installed in existing infrastructure. Evaluation of the feasibility and economical viability of rehabilitating the hydropower units has resulted in recommendations to install new and uprated units at most of the hydropower plants.

The peaking capability of the hydropower units is a valuable power resource in the region. Installing uprated units may cause changes to the operation of the power plants and changes to river flows below the projects. More capable units could cause increased discharge and more rapid rates of rise and fall in the river during power peaking operations. To assess these potential changes in daily river flows and stages an hourly discharge dynamic flow routing model will be developed by Nashville District. An assessment of the effects will then be made.

Initially the reach of the Cumberland River below Wolf Creek and Dale Hollow dams to the reservoir for Cordell Hull will be modeled, followed by the reach of the Cumberland River below Cordell Hull and Center Hill dams.

An hourly discharge schedule for the Cumberland River powerplants is needed as input into the flow routing model. HAC has been assigned the task of preparing 7-day hydrographs for project releases on an hourly time-step for this purpose.

The HAC performed a hydropower analysis of the hydropower potential for new units using output from the river basin hydrologic model HEC-5 which routed water through the system with the new units installed using a daily time-step. This modeling effort was performed as part of the Major Rehabilitation and Evaluation Reports (MRER) for Wolf Creek and Center Hill projects. These analyses were carried out assuming the new units would be operated at best efficiency output performance.

The HAC then developed hourly schedules for flow releases from dams where new units are to be installed. While it is recognized that there are many complex factors that have an effect on the scheduling of hydropower plants, the analysis was restricted to the project operating data (1987-1998) available in HAC files, updated information through 2001 was recently furnished by Nashville District. Upon review of the critical period data (June through August) there were incomplete or missing data in 1987, 1988 and 2001. Hourly observed data from those years were eliminated from the analysis. Daily data from the hydrologic routing model HEC-5 for both the Base Case and the Rehab Case were from 1968 through 1998. Turbine performance characteristics of both the existing and new units furnished by the Hydroelectric Design Center (HDC).

Study Methodology

Daily discharge data were extracted for the critical period (June through August) from the HEC-5 Model runs for Alternative 1 of the Wolf Creek MRER, which is the base case or existing condition with units at 45 MW, and Alternative 3 which is the up-rated units at 67.2 MW. The HEC-5 model simulated the period 1930-1998. The critical period data extracted for each year and the weekly volume was computed and flow duration developed. The weekly volume that corresponded to the 10%, 50%,

and 90% flow duration were selected for this analysis to represent high, medium, and low flow conditions under which to generate power at Wolf Creek hydropower plant.

Data from the critical period was selected for the analysis because those months have typical hydropower plant operations that consistently result in the largest daily swings in discharge to meet peak demands for power. See Figure 2 below. Note that the critical period values denoted by data point markers.
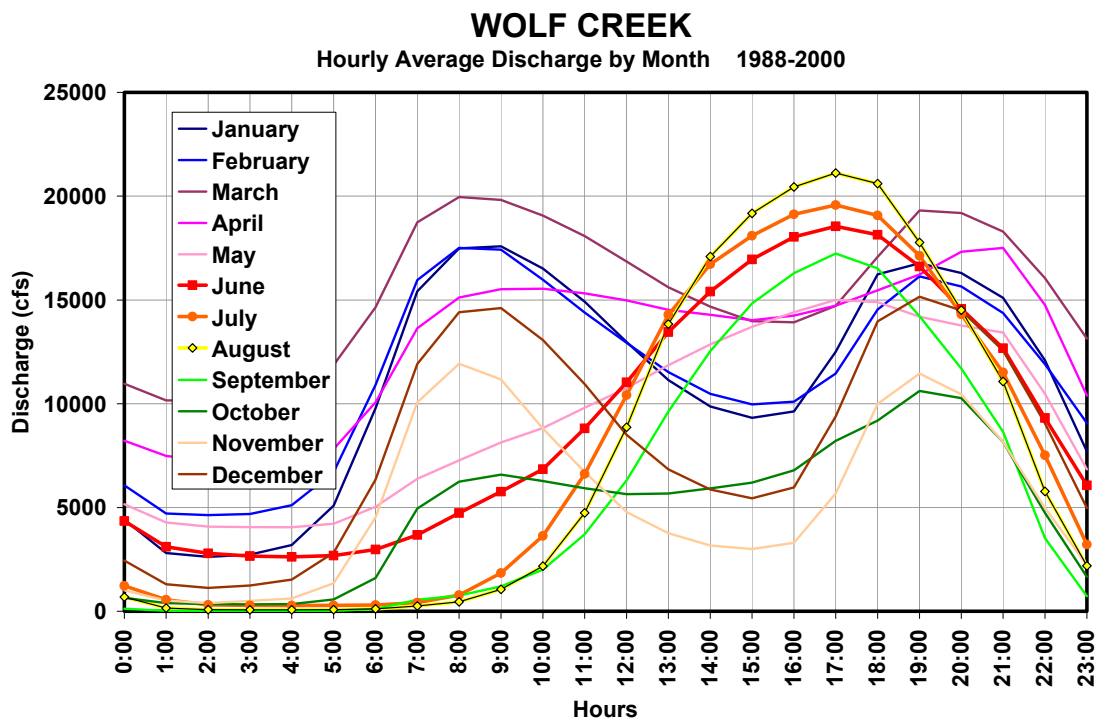
WOLF CREEK

Hourly Average Discharge by Month   1988-2000

Figure 2. Hourly discharge by month.

A one-week sequence was selected from the HEC-5 model runs for this analysis to preserve the water regulation "rules and limits" coded into the model throughout the basin that changes as a result of turbine/generator uprates. The weekly distribution of the daily flow volumes is shown in Figure 3 below.
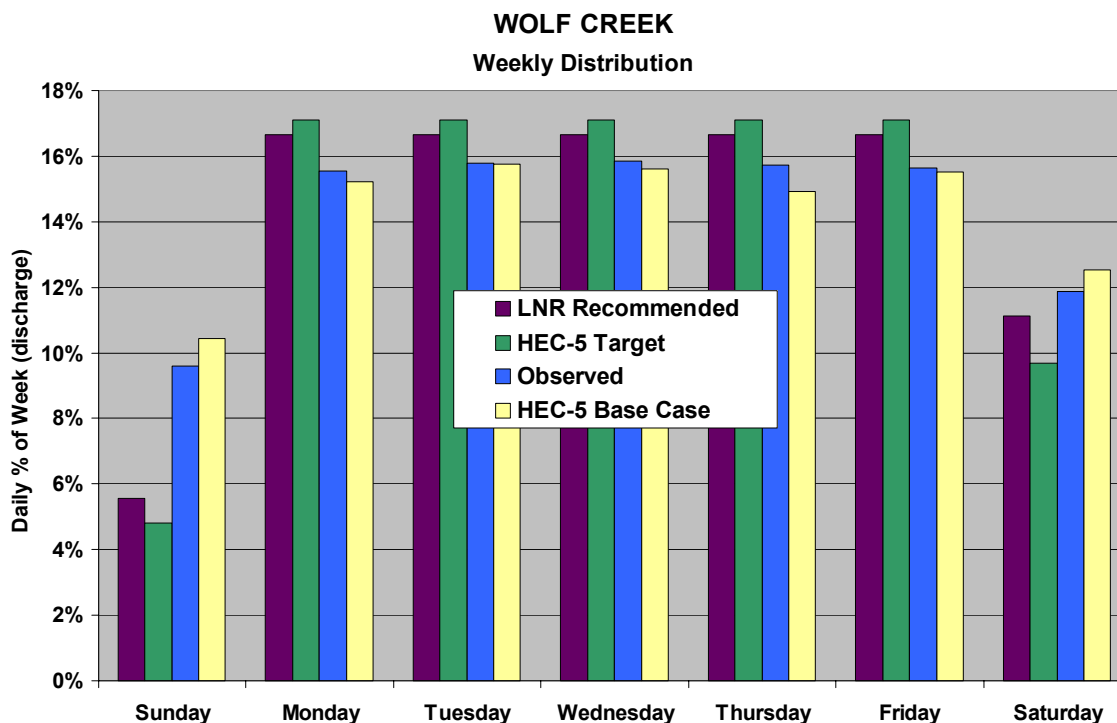
WOLF CREEK

Weekly Distribution

Figure 3. Weekly distribution of daily average discharge volume

Weekly flow volumes from the annual critical period (June-August) in the HEC-5 analysis were computed for the Wolf Creek MRER Alternative 3 (rehab case).

The weeks closest to the 10%, 50%, and 90% weekly flow volume that had a weekly flow distribution similar to the average were used as the basis for developing the 7-day hydrographs shown in Table 2 below. Note: DSF is in units of a daily flow volume, day-second-foot.

Table 2. Exceedence volumes and selected weeks volumes

Percent Exceedence	Rehab Weekly DSF	Week Ending date	Week DSF
10.0	76,728	20-Aug-78	73,391
50.0	41,493	26-Jul-87	41,493
90.0	26,199	10-Aug-97	27,029

The week ending 26-Jul-87 (see Table 3 below) is used in this report to illustrate the methodologies. The column labeled ALT 3 BG is the daily average flow in units of DSF from the HEC-5 model simulation for the selected unit rehabilitation case from the Wolf Creek MRER with the units operating at best gate (best efficiency).

Table 3. Selected week for 50% exceedence

Weekday	Date	Alt3 BG Flow
Monday	20-Jul-87	5,204
Tuesday	21-Jul-87	7,035
Wednesday	22-Jul-87	6,857
Thursday	23-Jul-87	6,815
Friday	24-Jul-87	6,495
Saturday	25-Jul-87	5,399
Sunday	26-Jul-87	3,688

Weekly Volume (DSF)   41,493

It is worth noting that for this week the average flow for Monday is un-typically lower than the remaining weekdays though the weekly volume is near the 50% exceedence value. For the period of record (1989-2000), the average daily peaks and average daily discharges for Monday through Friday are very close to equal, with Saturdays slightly lower and Sundays slightly lower than Saturdays as illustrated in Figure 4 below.
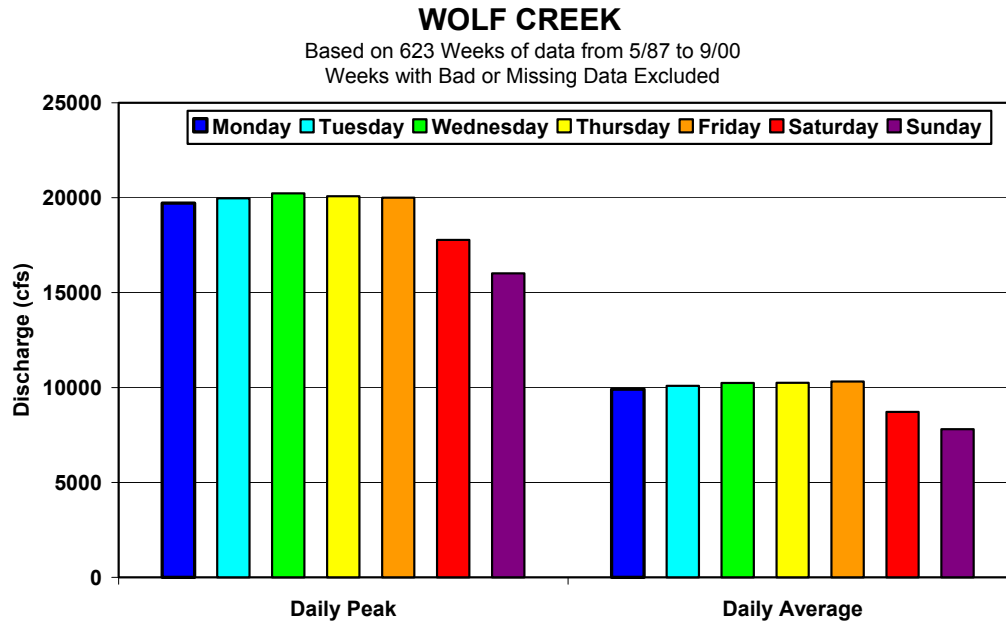

Figure 4. Daily peak and average discharge

The untypical Monday flow in the selected week should not affect the river stage change rates later in the week and the potential operating range of the new units will be shown in the other days. (Subsequent analyses will be based on a week starting

with Sunday that corresponds to the dispatch cycle currently used by Nashville District.)

Following are descriptions of several methodologies evaluated for parsing the daily discharge data to hourly discharge schedule. Each approach was evaluated for reasonableness and a final method was selected to develop the hydrographs.

Method 1 – For Method 1, first compute the average discharge in each hour of the week of the critical period (June-August) in the period of record (1988-2000). Then compute the ratio of the hour average to the sum of the hour averages for the day. This is the hourly fraction of the daily flow volume for each day of the week (area under the daily hydrograph is unity). Noted that the higher peaks in Figure 5 indicate only that a higher portion of the daily flow is assigned at that hour (the hydrograph is "peakier" on the weekend).
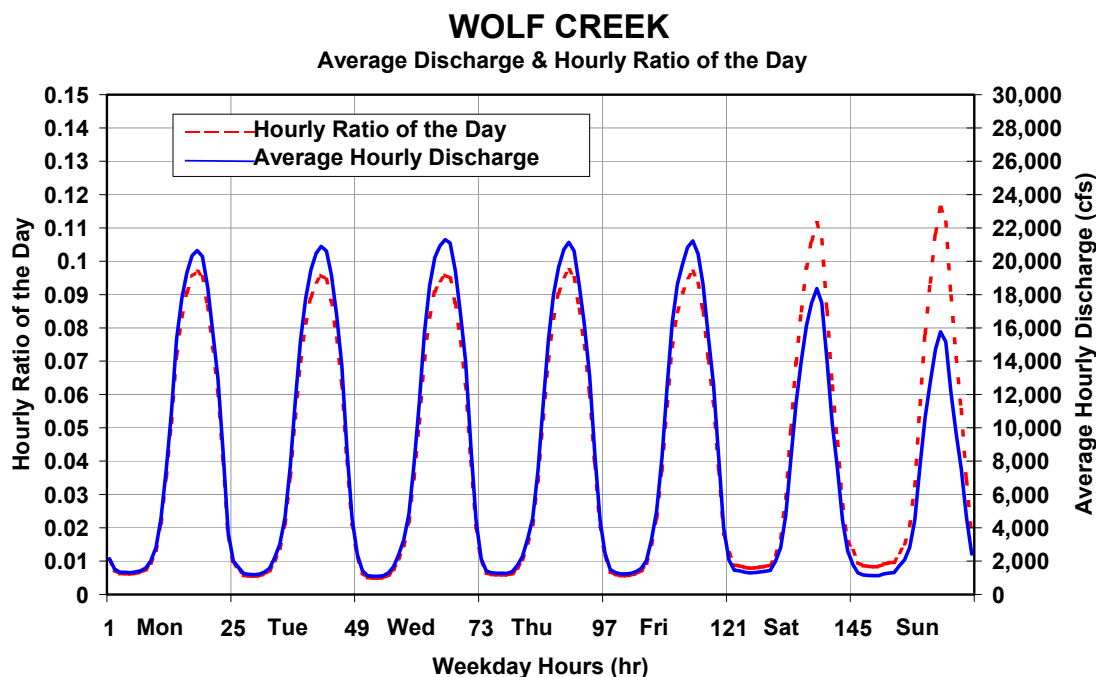
Figure 5. Hourly discharge

The daily flows in Table 3 were then disaggregated (distributed) into hourly flows by multiplying the daily flow/volumes by the hourly fraction to compute the hourly flow schedule.

In the Table 4 below, the days in the first column are numbered from Monday through Sunday. In the second column the hour of the day is based on a 24-hour clock. The "Hourly Ratio" in the third column is the average hourly portion of the daily flow. The column labeled "Alt 3 Hourly Flow Computed" is the hourly flow from the rehabilitated units, which is obtained by multiplying the daily flow by the

hourly ratio. The last column is the daily sum of the hourly flow/volumes to verify that the parsed volume is equal to the daily flow volume.

Table 4. Disaggregation of the daily discharge volume

Day	Hour	Hourly Ratio	Alt 3 Hourly Flow Computed	Daily Volume
Monday	100	0.0100	1,255	
Monday	200	0.0072	897	
Monday	300	0.0062	780	
Monday	400	0.0062	780	
Monday	500	0.0061	764	
Monday	600	0.0064	793	
Monday	700	0.0067	831	
Monday	800	0.0074	926	
Monday	900	0.0094	1,179	
Monday	1000	0.0133	1,658	
Monday	1100	0.0214	2,679	
Monday	1200	0.0353	4,405	
Monday	1300	0.0517	6,455	
Monday	1400	0.0718	8,973	
Monday	1500	0.0834	10,417	
Monday	1600	0.0907	11,329	
Monday	1700	0.0954	11,920	
Monday	1800	0.0969	12,102	
Monday	1900	0.0953	11,900	
Monday	2000	0.0866	10,810	
Monday	2100	0.0741	9,259	
Monday	2200	0.0608	7,592	
Monday	2300	0.0402	5,022	
Monday	2400	0.0174	2,170	5,204
Tuesday	100	0.0092	1,556	
Tuesday	200	0.0074	1,255	
Tuesday	300	0.0057	967	
...	...	...	...	...
...	...	...	...	...
Sunday	1400	0.0571	5,052	
Sunday	1500	0.0784	6,939	
Sunday	1600	0.0938	8,305	
Sunday	1700	0.1086	9,613	
Sunday	1800	0.1161	10,279	
Sunday	1900	0.1117	9,886	
Sunday	2000	0.0895	7,922	
Sunday	2100	0.0711	6,291	
Sunday	2200	0.0554	4,904	
Sunday	2300	0.0343	3,031	
Sunday	2400	0.0179	1,584	3,688

Figure 6 is a graphical representation of the result of this method for the 50% volume exceedence.

WOLF CREEK
7-Day Hourly Hydrograph - 50% Exceedence
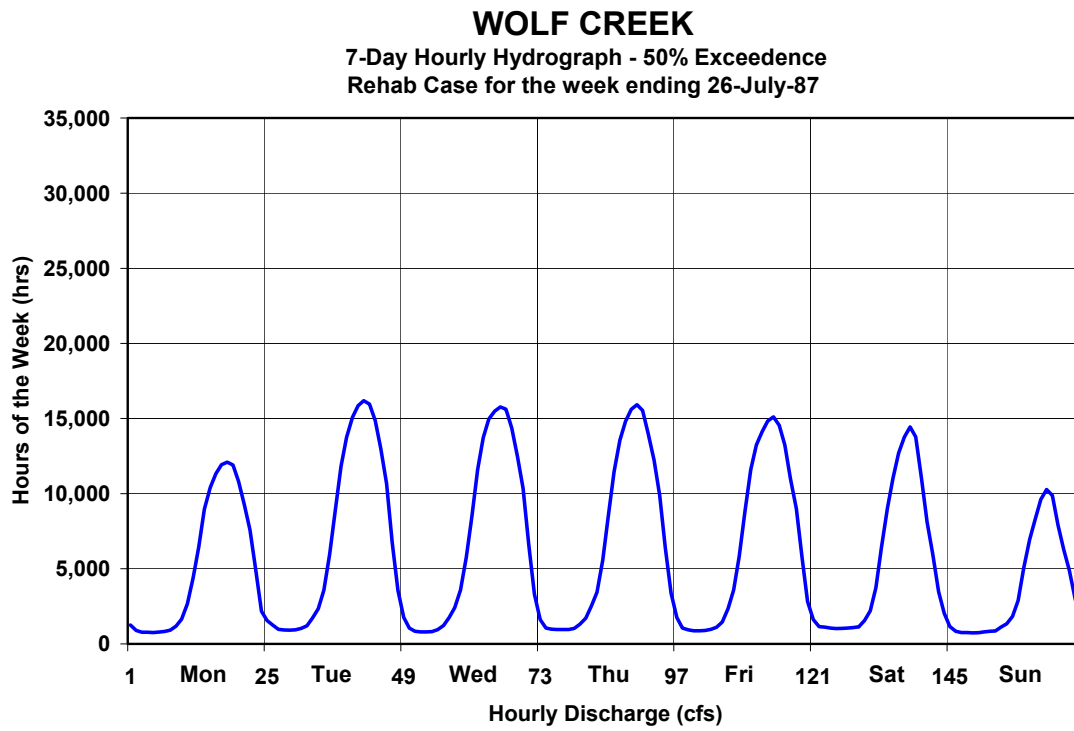**Rehab Case for the week ending 26-July-87**

Figure 6. Method 1, 7-day hydrograph

Method 2 – This method is a refinement to Method 1. The usual unit dispatch is to operate a unit at best efficiency. In Method 2 the hourly discharge was rounded to the nearest whole unit discharge at best efficiency with an upper limit of plant capacity. The hourly discharges assigned in this way were shaped proportionally to the daily average discharge. The result of applying Method 2 is shown in Figure 7 below.
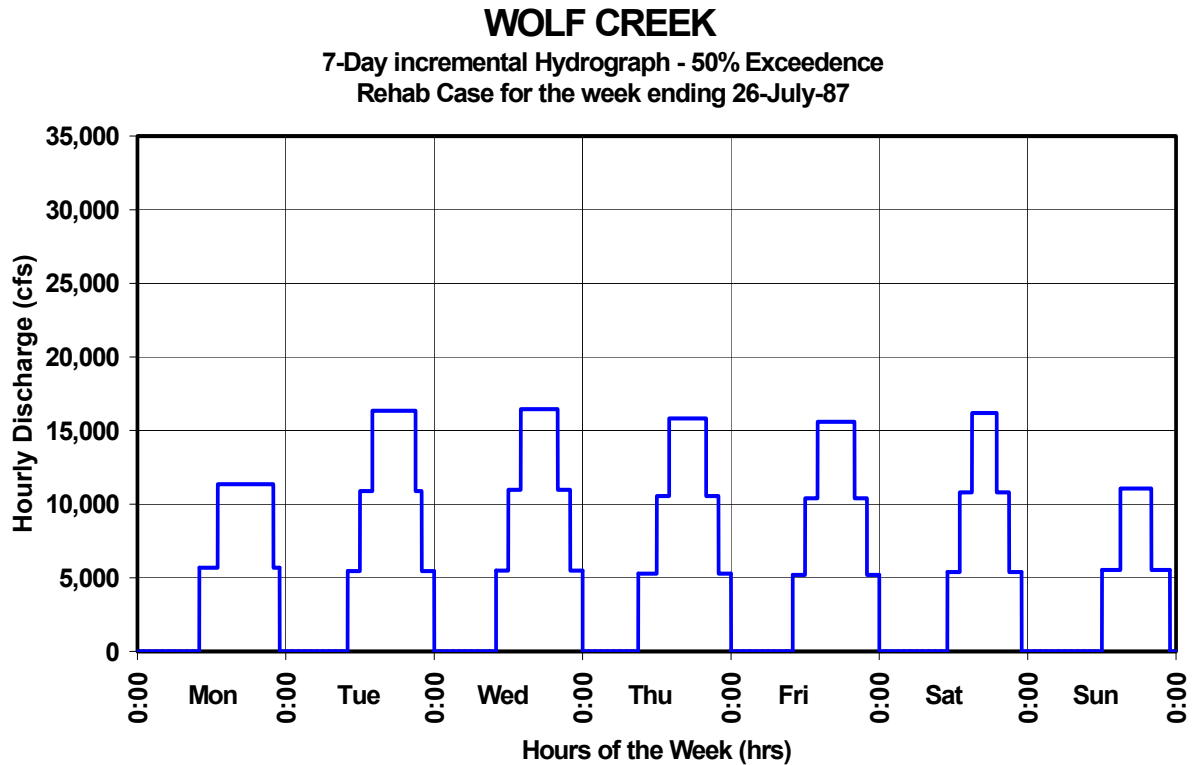

Figure 7. Method 2, 7-day-hydrograph

Method 3. Method 3 is a further refinement of Methods 1 and 2. Data are selected from the hourly observed 1988-200 period of record representing weeks whose volume is within ±10% of the selected flow/volume to develop hourly ratio sequences corresponding to 10%, 50%, 90% exceedence. Figure 8 shows the result of applying Method 3 to the week of 26-July-87 (50% exceedence volume).
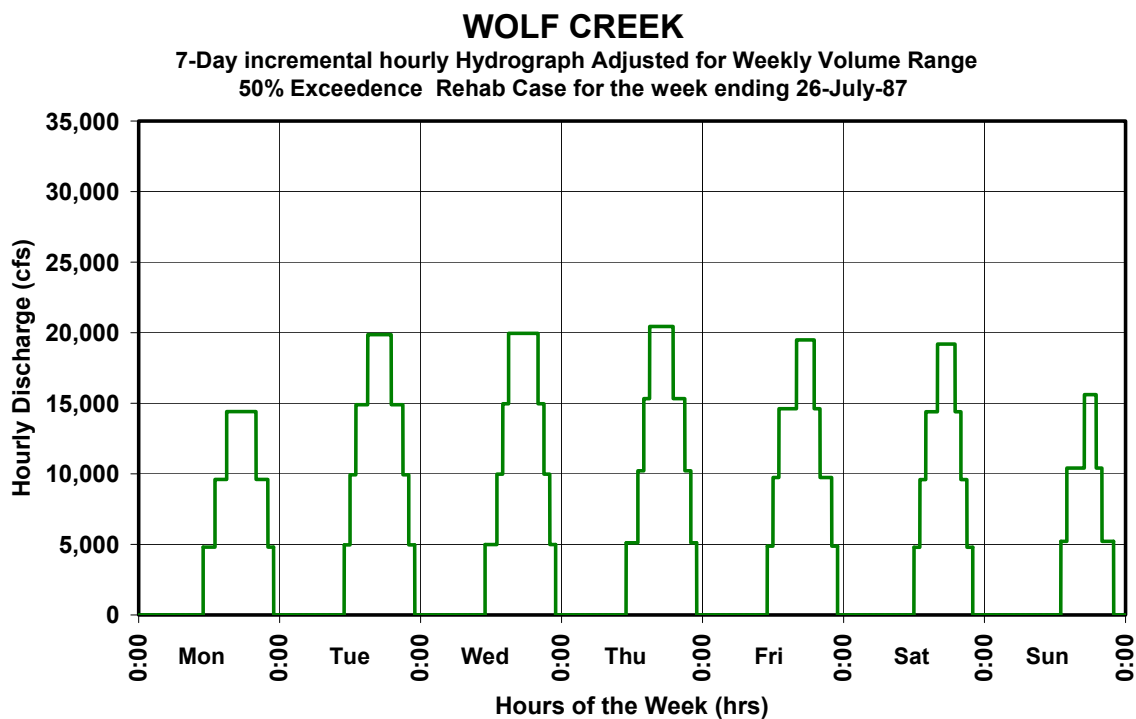

Figure 8. Method 3, 7-day hydrograph

Method 4 - Method 4 resulted from a review of a "typical schedule" operating the power plant at a capacity and discharge rate of change limit of three units per hour. This was taken from a document dated 14-August 1986 furnished HAC by Nashville District. The following observations were made from the document. Initial generation was started with three units. The start time was determined by the energy demand of the day. The following hour three units were added for full plant capacity. During weekdays, the plant was reduced three units at 1900 hours, reduced two more units at 2000 hours, and the last unit was turned off at 2100 hours. During weekends, the plant reduced generation to three units at 1800 hours and stopped the remaining three units at 1900 hours. Once the plant stopped generating, it remained off-line until the following day. The result of applying this approach and adjusting the hourly volume to the daily volume is shown in Figure 9 below.
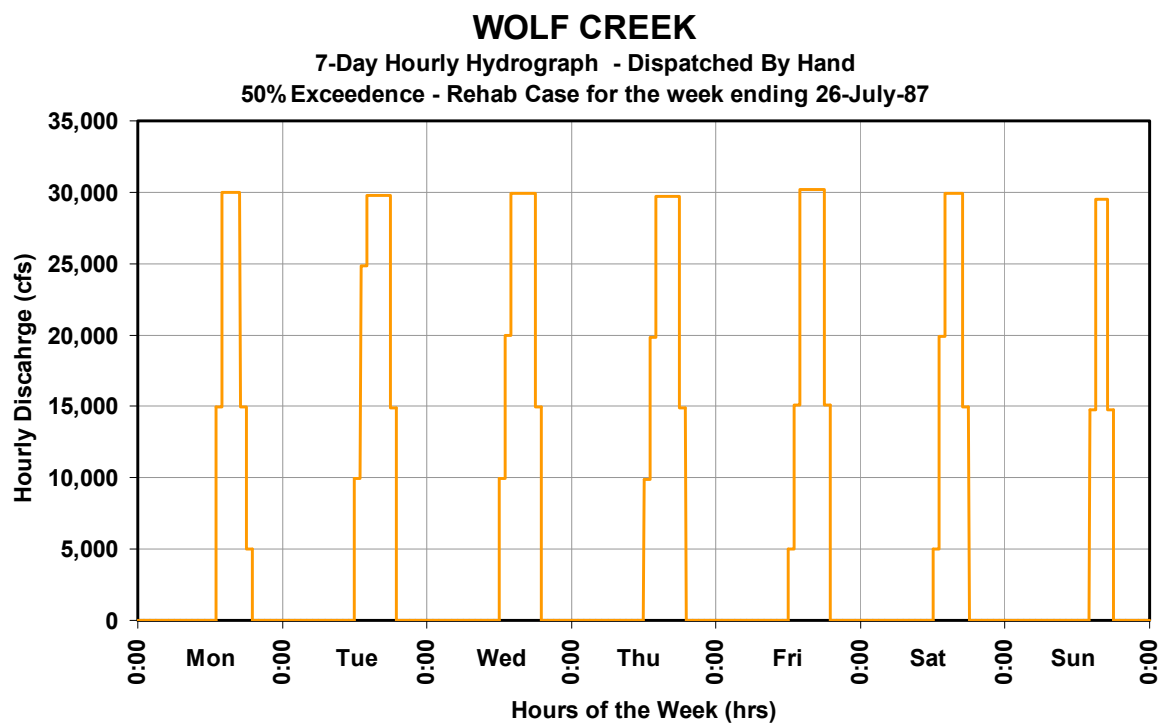
WOLF CREEK
7-Day Hourly Hydrograph - Dispatched By Hand
50% Exceedence - Rehab Case for the week ending 26-July-87

Figure 9. Method 4, 7-day hydrograph

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Method 5 - Method 5 uses the hourly ratio sequences from the selected data to determine the hour of the daily peak discharge. This assumes the plant with new units will peak at the same hour as it did historically. The plant is dispatched to ramp up or down at three units per hour operating at capacity to the extent of the daily discharge volume. The plant is operated at 6-unit capacity on weekdays, 5-unit capacity on Saturdays, and 4-unit capacity on Sundays based on the analysis and results displayed in Graph 3. There is a 1-hour pulsing operation performed in the 12th hour of no a generation period. The results applying Method 5 are shown in Figure 10 below.

WOLF CREEK
7-Day Hourly Hydrograph - Dispatched On Peak
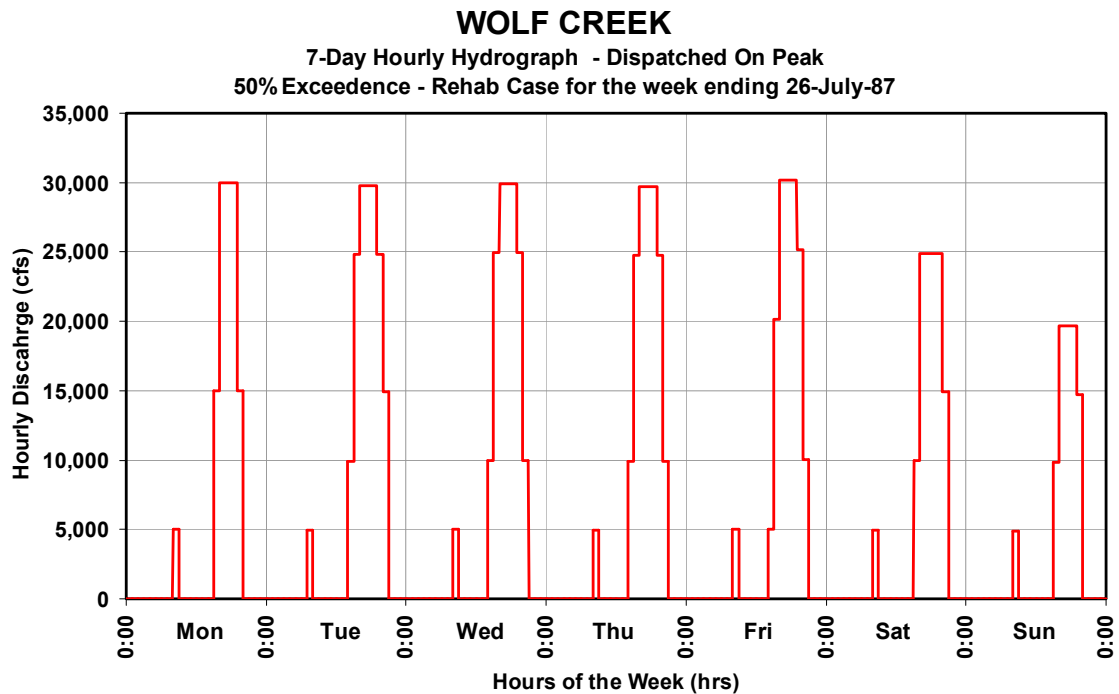**50% Exceedence - Rehab Case for the week ending 26-July-87**

Figure 10. Method 5, 7-day-hydrograph

Ramping rates at Wolf Creek hydropower plant are presently set at three units per hour. It should be noted that the exiting units have a discharge of about 3,900 cfs at a gross head of 160 feet at best efficiency, while the new units would discharge about 5,000 cfs. The present ramping rate then is 11,700 cfs per hour but with the new units it would be about 15,000 cfs per hour. With a ramping rate of two units per hour with the new units the ramping rate would be reduced to 10,000 cfs per hour. This should be evaluated further in subsequent analyses.

It should be recognized that the results of Method 5 represent a reasonably likely operation pattern, but peak discharges on a given weekday (Monday to Friday) could be lower and peak discharges on weekend days (Saturday and Sunday) could be higher, up to the maximum plant capability depending on plant availability and overall water and/or power system conditions and needs.

It is possible that the additional capacity of the units could be used to provide system reserves (spinning and non-spinning) but since the objective is to evaluate potential flow changes it is assume units are discharged to their maximum capability.

Discussion

The following discussion shows the evolution of thinking behind the development of methodologies for deriving hourly discharge data from daily discharge data utilizing the HEC-5 simulations for the Wolf Creek MRER.

Method 1 is an aggregation of existing operations based on the old units and thus represents an average schedule used to represent high, medium, and low flow and power demand schedules. This method fixes the duration of the daily schedule regardless of the demand or new plant capability. The new capacity is not fully utilized. The primary benefit is additional energy due to efficiency improvements but does not take advantage of the additional capacity. In this method the capacity required to develop the daily flow sometimes unrealistically requires discharges above plant capability. Units are dispatched at fractional unit discharge without regard for efficiency.

Method 2 limits the unit dispatch to hourly increments ("on" or "off" at best efficiency), which is more realistic, yet still sometimes beyond plant capability.

Method 3 allows for the dispatch to be tailored to allow for variation in both capacity and generation duration when daily flow volume varies. Dispatch is in realistic increments and discharge is rarely driven beyond plant capability.

Method 4 assumes full use of the plant capacity within the ramping rate limit of three units per hour. This approach to dispatch does not allow the flexibility to meet loads effectively when there is not enough water to generate for the entire period of daily peak demand. The resulting hourly project releases yielded by this procedure are generally higher than those in the record of observed operations for all but the higher flow days.

Method 5 results in hydrographs whose peak flows are on the high side of normal operations but represent a reasonable operation of the new units and 1-hour pulse in 12 hours without generation. Typically weekend generation is less than weekdays. Actual operations will be subject to real-time operational conditions of the regional power system demands. Smaller peak discharge and longer duration peak discharges are nearer to average conditions at the selected weekly flow volumes. Minimum flows (hatchery flow) will be added to the hydrographs.

In Figure11 below Methods 2, 3, and 5 are applied to the base case for the 50% exceedence weekly volume. Included is the average of the hourly operating data from weeks where the flow volume +10% of the 50% exceedence

WOLF CREEK
7-Day Hydrograph - Methods Comparison
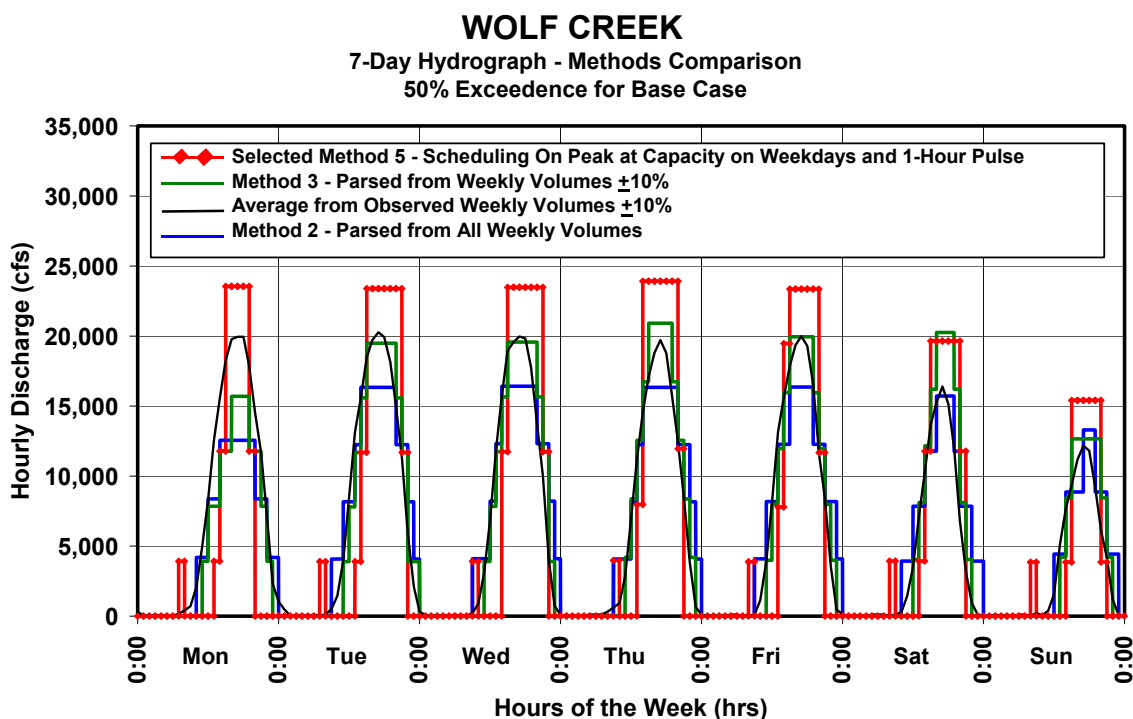### 50% Exceedence for Base Case

Figure 11. Methods 2,3,and 5 comparison

Method 5 yields results consistent with hourly dispatch at unit capacity, dispatch at less than plant capability on weekends, and generation duration that changes with water volume available as shown in Figure 10 above. It should be recognized that this represents a reasonably likely operation pattern, but peak discharges on a given weekday (Monday to Friday) could be lower and peak discharges on weekend days (Saturday and Sunday) could be higher, up to the maximum plant capability depending on plant availability and overall water and/or power system conditions and needs.

Subsequent comments dated 14 March 2003 and discussion with Nashville District Staff (meeting summary dated 24 March 2003) resulted in additional modification of the method of developing the 7-Day Hydrographs.

- It was revealed that the District's weekly hydropower coordination was based on a week from Sunday through Saturday thus the analysis was shifted as a result.

- One of the main premises of hydropower plant upgrade program is there are no shifts in the weekly distribution of the daily average discharge from the

projects where turbine/generator units are upgraded. The daily discharge volume for both the Base Case and the Rehab Case are identical.

- The representative week chosen for this report did not have the same distribution of daily average discharge as the "typical" week in the critical period; therefore, should not be used as the basis from development of the 7-day hydrograph. The observed average daily discharge volume for the critical period was used to develop the "typical" weekly distribution.

Conclusion

As a result of a subsequent review of this document the following guidance was agreed upon:

1. Data from the critical period of June through August will be the basis for the analyses.

2. 7-day hydrograph will be based on a dispatch week of Sunday through Saturday.

3. 7-day hydrograph will be based on weekly discharge volumes from the HEC-5 model output for Alternative 1 (Base Case) at the 10%, 50%, and 90% exceedence volumes.

4. Weekly volume for both the Base Case and the Rehab Case will be identical.

5. The weekly volume will be distributed in accordance with the observed average daily volume, which is nearly like the distribution shown in HEC-5 Alternative 1.

6. The hourly distribution on weekdays will be made at the hydropower plant capability subject to the hourly rate-of-change limit, the minimum flow or hatchery release, he daily 1-hour pulse during extended periods without generation, and minimum (hatchery) flow.

7. The generation period, "peaking operation", will be timed to coincide with the daily average peak flow.

Results

Following are the complete set of 7-day hydrographs and tables for Wolf Creek hydropower plant based on guidelines in the final conclusion above.

Table 5. Basic data for computation of the 7-day hydrographs

	10% Exceedence			Base Case		Rehab Case	
	Distribution	Discharge cfs	Head ft	Capablilty	Unit Hours	Capablilty	Unit Hours
Sunday	10%	7,553	160.0	3,876	47	5,022	36
Monday	16%	12,229	161.0	3,859	76	5,029	58
Tuesday	16%	12,423	157.5	3,926	76	5,006	59
Wednesda	16%	12,468	157.9	3,919	76	5,008	60
Thursday	16%	12,377	157.6	3,923	76	5,007	59
Friday	16%	12,316	157.0	3,937	75	5,003	59
Saturday	12%	9,349	157.2	3,932	57	5,004	45
Week	100%	78,713	Observed				

	50% Exceedence			Base Case		Rehab Case	
	Distribution	Discharge cfs	Head ft	Capablilty	Unit Hours	Capablilty	Unit Hours
Sunday	10%	3,859	159.7	3,883	24	5,020	18
Monday	16%	6,248	160.1	3,874	39	5,023	30
Tuesday	16%	6,347	158.6	3,903	39	5,013	30
Wednesda	16%	6,370	158.0	3,915	39	5,010	30
Thursday	16%	6,323	157.7	3,923	39	5,007	30
Friday	16%	6,292	157.6	3,925	38	5,007	30
Saturday	12%	4,776	157.3	3,931	29	5,005	23
Week	100%	40,215	Observed				

	90% Exceedence			Base Case		Rehab Case	
	Distribution	Discharge cfs	Head ft	Capablilty	Unit Hours	Capablilty	Unit Hours
Sunday	10%	2,578	167.9	3,744	16	5,076	12
Monday	16%	4,174	169.0	3,728	27	5,085	20
Tuesday	16%	4,241	167.7	3,748	27	5,075	20
Wednesda	16%	4,256	167.0	3,757	27	5,070	20
Thursday	16%	4,225	166.8	3,761	27	5,068	20
Friday	16%	4,204	166.7	3,761	27	5,068	20
Saturday	12%	3,191	166.4	3,767	20	5,066	15
Week	100%	26,870	Observed				

Table 6. Wolf Creek 7-day hydrographs

Rate-of-Change Day	Hour	Base Case 3 Units/hr cfs	Rehab Case 3 Units/hr cfs	Rehab Case 2 Units/hr cfs	Rate-of-Change Day	Hour	Base Case 3 Units/hr cfs	Rehab Case 3 Units/hr cfs	Rehab Case 2 Units/hr cfs	Rate-of-Change Day	Hour	Base Case 3 Units/hr cfs	Rehab Case 3 Units/hr cfs	Rehab Case 2 Units/hr cfs	Rate-of-Change Day	Hour	Base Case 3 Units/hr cfs	Rehab Case 3 Units/hr cfs	Rehab Case 2 Units/hr cfs
Sun	1	20	20	20	Tue	1	20	20	20	Thu	1	20	20	20	Sat	1	20	20	20
Sun	2	20	20	20	Tue	2	20	20	20	Thu	2	20	20	20	Sat	2	20	20	20
Sun	3	20	20	20	Tue	3	20	20	20	Thu	3	20	20	20	Sat	3	20	20	20
Sun	4	20	20	20	Tue	4	20	20	20	Thu	4	20	20	20	Sat	4	20	20	20
Sun	5	20	20	20	Tue	5	20	20	20	Thu	5	20	20	20	Sat	5	20	20	20
Sun	6	20	20	20	Tue	6	20	20	20	Thu	6	20	20	20	Sat	6	20	20	20
Sun	7	20	20	20	Tue	7	20	20	20	Thu	7	20	20	20	Sat	7	20	20	20
Sun	8	20	20	20	Tue	8	20	20	20	Thu	8	20	20	20	Sat	8	20	20	20
Sun	9	20	20	20	Tue	9	20	20	20	Thu	9	20	20	20	Sat	9	20	20	20
Sun	10	20	5,042	5,042	Tue	10	20	5,065	20	Thu	10	20	5,047	20	Sat	10	20	4,995	4,995
Sun	11	3,866	20	20	Tue	11	11,770	20	5,065	Thu	11	11,727	20	5,047	Sat	11	20	20	20
Sun	12	11,559	20	20	Tue	12	23,520	20	10,110	Thu	12	23,433	15,100	10,073	Sat	12	11,804	20	20
Sun	13	15,406	15,085	10,063	Tue	13	23,520	15,156	20,201	Thu	13	23,433	30,180	20,126	Sat	13	19,659	20	9,971
Sun	14	15,406	20,107	20,107	Tue	14	23,520	30,291	30,291	Thu	14	23,433	30,180	30,180	Sat	14	19,659	14,946	19,921
Sun	15	15,406	20,107	20,107	Tue	15	23,520	30,291	30,291	Thu	15	23,433	30,180	30,180	Sat	15	19,659	24,897	24,897
Sun	16	15,406	20,107	20,107	Tue	16	23,520	30,291	30,291	Thu	16	23,433	30,180	30,180	Sat	16	19,659	24,897	24,897
Sun	17	15,406	20,107	20,107	Tue	17	23,520	30,291	30,291	Thu	17	23,433	30,180	30,180	Sat	17	19,659	24,897	24,897
Sun	18	15,406	20,107	20,107	Tue	18	23,520	30,291	30,291	Thu	18	23,433	30,180	30,180	Sat	18	19,659	24,897	24,897
Sun	19	15,406	20,107	20,107	Tue	19	23,520	30,291	30,291	Thu	19	23,433	30,180	30,180	Sat	19	19,659	24,897	24,897
Sun	20	15,406	20,107	20,107	Tue	20	23,520	30,291	30,291	Thu	20	23,433	30,180	30,180	Sat	20	19,659	24,897	24,897
Sun	21	15,406	15,085	15,085	Tue	21	23,520	30,291	25,246	Thu	21	23,433	25,153	25,153	Sat	21	19,659	24,897	19,921
Sun	22	15,406	5,042	10,063	Tue	22	23,520	25,246	15,156	Thu	22	23,433	10,073	15,100	Sat	22	19,659	19,921	14,946
Sun	23	11,559	20	20	Tue	23	19,603	10,110	10,110	Thu	23	19,531	20	10,073	Sat	23	15,732	9,971	4,995
Sun	24	20	20	20	Tue	24	7,853	20	20	Thu	24	7,824	20	20	Sat	24	20	20	20
Mon	1	20	20	20	Wed	1	20	20	20	Fri	1	20	20	20					
Mon	2	20	20	20	Wed	2	20	20	20	Fri	2	20	20	20					
Mon	3	20	20	20	Wed	3	20	20	20	Fri	3	20	20	20					
Mon	4	20	20	20	Wed	4	20	20	20	Fri	4	20	20	20					
Mon	5	20	20	20	Wed	5	20	20	20	Fri	5	20	20	20					
Mon	6	20	20	20	Wed	6	20	20	20	Fri	6	20	20	20					
Mon	7	20	20	20	Wed	7	20	20	20	Fri	7	20	20	20					
Mon	8	20	20	20	Wed	8	20	20	20	Fri	8	20	20	20					
Mon	9	20	20	20	Wed	9	20	20	20	Fri	9	20	20	20					
Mon	10	20	5,072	5,072	Wed	10	20	4,999	20	Fri	10	20	5,022	20					
Mon	11	11,586	20	20	Wed	11	11,813	20	4,999	Fri	11	11,824	20	5,022					
Mon	12	23,152	20	10,124	Wed	12	23,606	14,958	9,978	Fri	12	23,628	15,025	5,022					
Mon	13	23,152	15,175	20,227	Wed	13	23,606	29,895	19,937	Fri	13	23,628	30,030	20,027					
Mon	14	23,152	30,331	30,331	Wed	14	23,606	29,895	29,895	Fri	14	23,628	30,030	30,030					
Mon	15	23,152	30,331	30,331	Wed	15	23,606	29,895	29,895	Fri	15	23,628	30,030	30,030					
Mon	16	23,152	30,331	30,331	Wed	16	23,606	29,895	29,895	Fri	16	23,628	30,030	30,030					
Mon	17	23,152	30,331	30,331	Wed	17	23,606	29,895	29,895	Fri	17	23,628	30,030	30,030					
Mon	18	23,152	30,331	30,331	Wed	18	23,606	29,895	29,895	Fri	18	23,628	30,030	30,030					
Mon	19	23,152	30,331	30,331	Wed	19	23,606	29,895	29,895	Fri	19	23,628	30,030	30,030					
Mon	20	23,152	30,331	30,331	Wed	20	23,606	29,895	29,895	Fri	20	23,628	30,030	30,030					
Mon	21	23,152	30,331	25,279	Wed	21	23,606	24,916	24,916	Fri	21	23,628	25,029	25,029					
Mon	22	23,152	20,227	15,175	Wed	22	23,606	14,958	19,937	Fri	22	23,628	10,023	20,027					
Mon	23	19,297	10,124	5,072	Wed	23	19,675	20	9,978	Fri	23	15,759	20	10,023					
Mon	24	7,731	20	20	Wed	24	7,882	20	20	Fri	24	7,889	20	20					

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WOLF CREEK
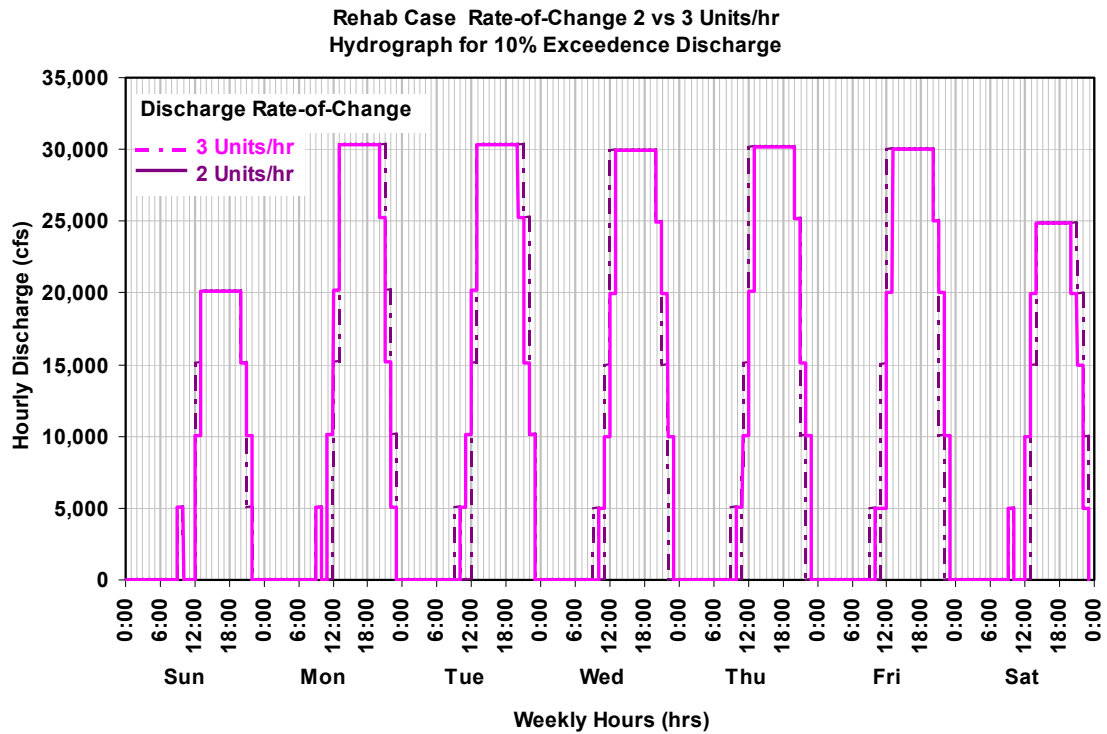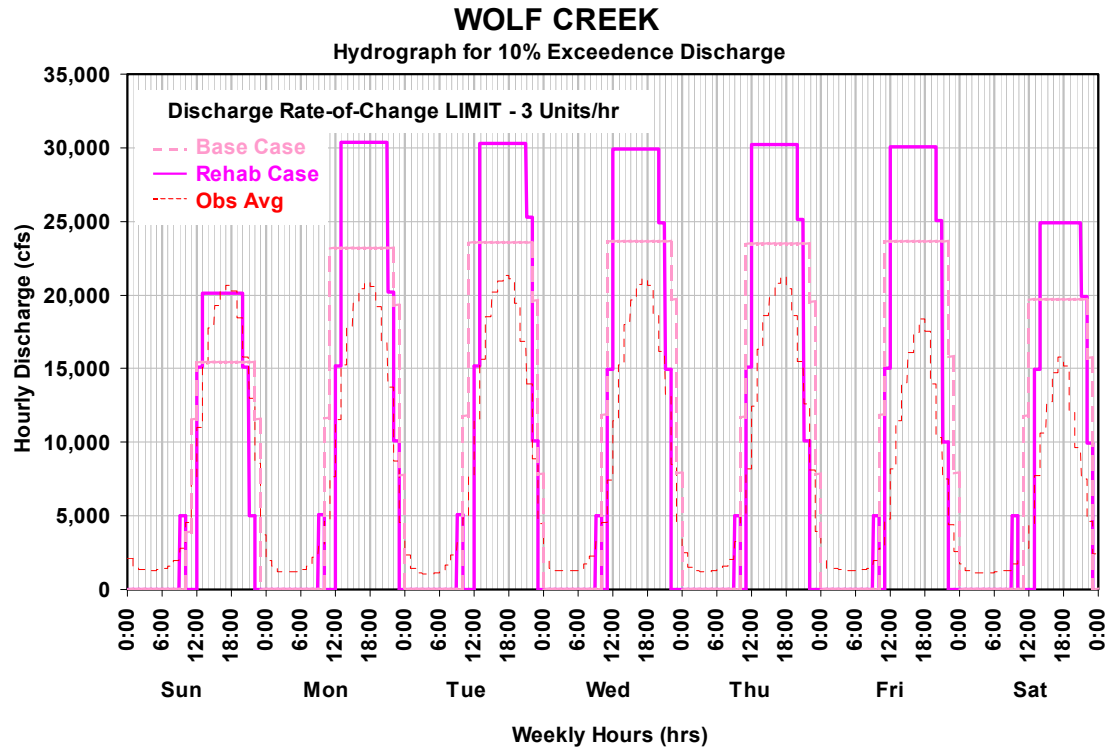
Hydrograph for 10% Exceedence Discharge

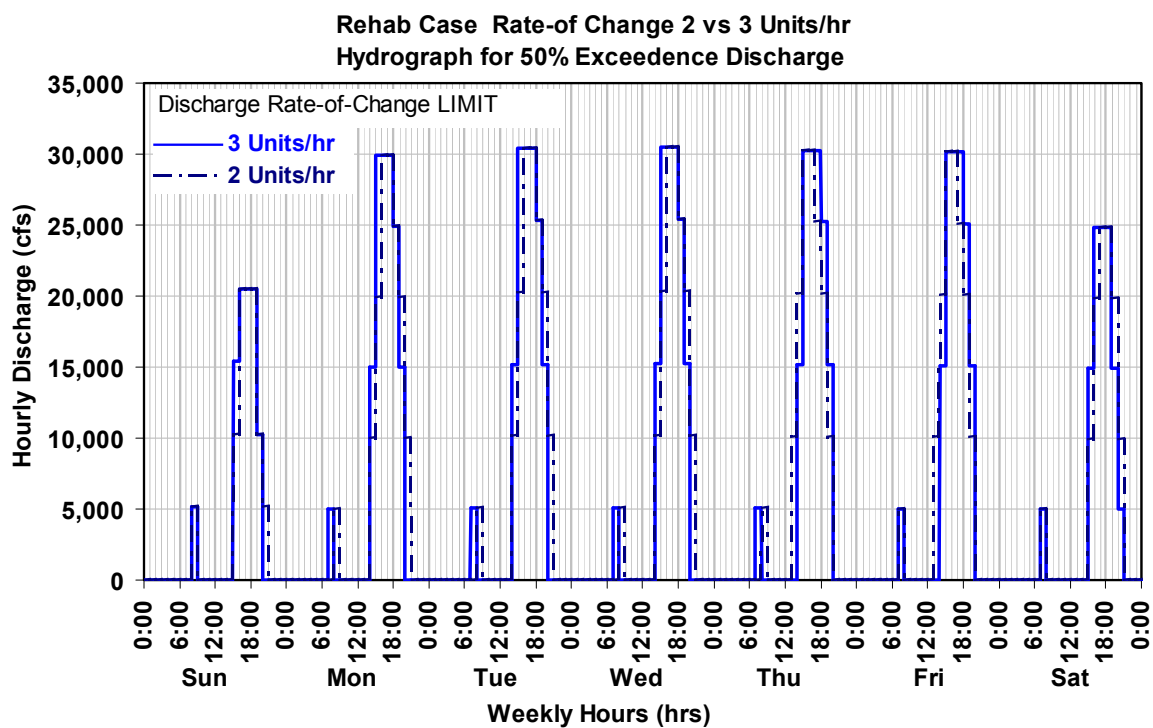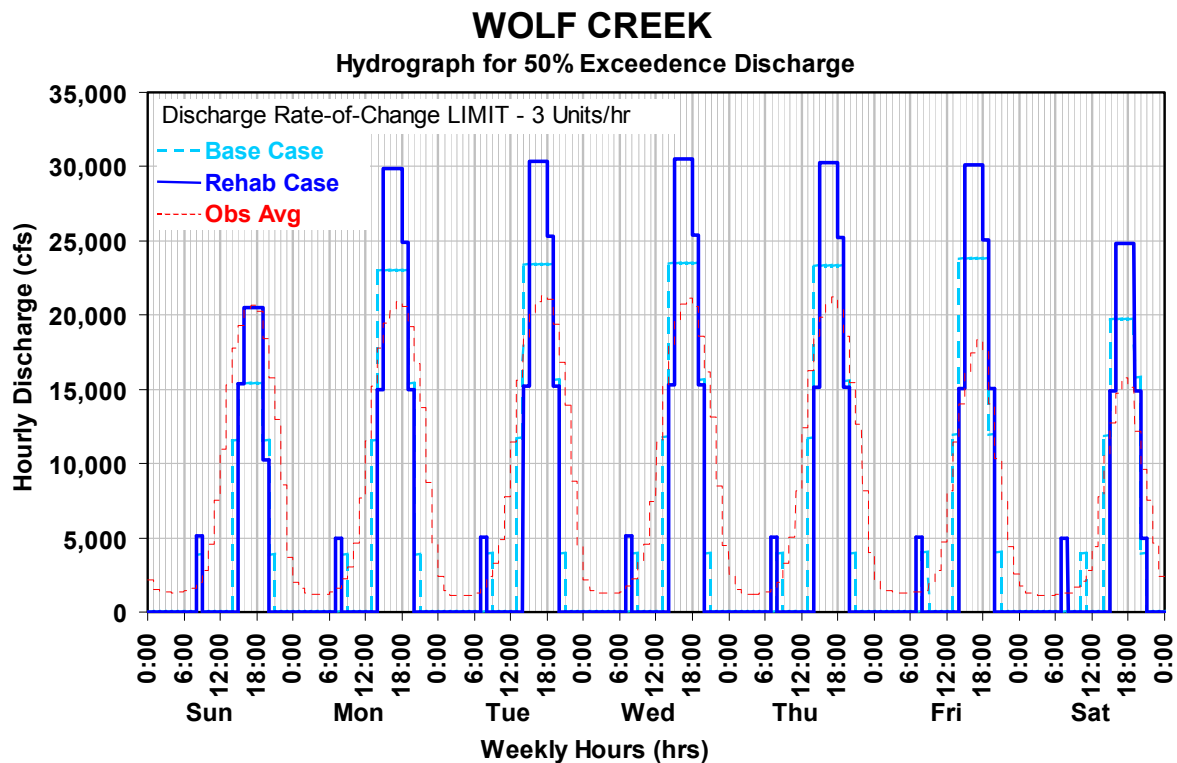**Figure 12**. 7-day hydrographs for 10% exceedence
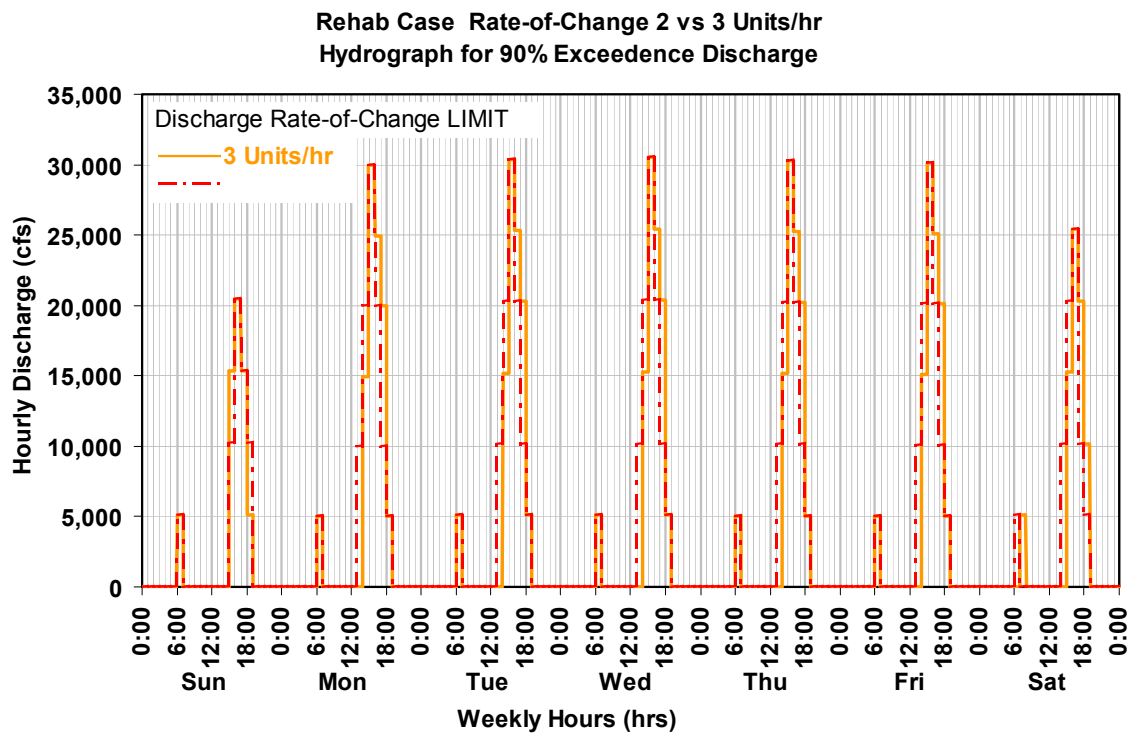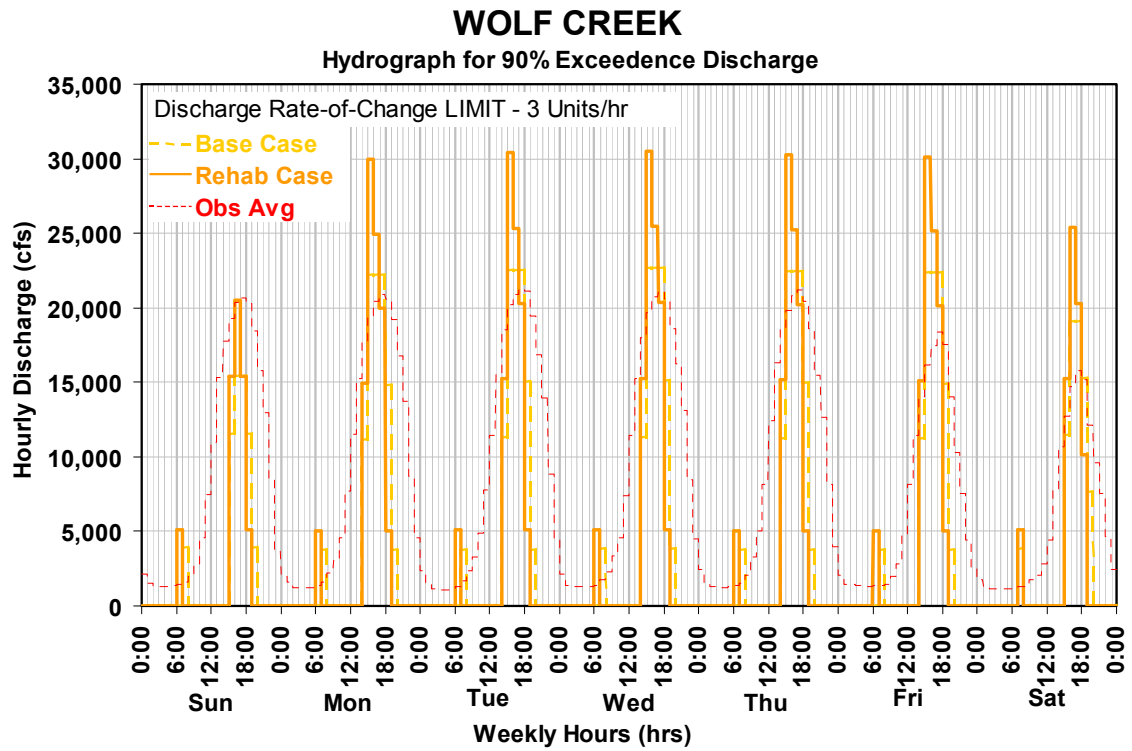
Figure 13. 7-day hydrographs for 50% exceedence

Figure 14. 7-day hydrographs for 90% exceedence